REVIEW ARTICLE

Effectiveness of Multimedia Approaches in Embryology Teaching: A Scoping Review

Siti Nurma Hanim Hadie[1], Razif Dasiman[2], Noorkardiffa Syawalina Omar[3], Razif Abas[4]

[1] Department of Anatomy, School of Medical Sciences, Health Campus, Universiti Sains Malaysia, Kubang Kerian, Malaysia
[2] Department of Basic Sciences, Faculty of Health Sciences, Universiti Teknologi MARA Selangor, Puncak Alam, Malaysia
[3] Department of Obstetrics and Gynaecology, Faculty of Medicine, Universiti Teknologi MARA Selangor, Jalan Hospital, Sungai Buloh, Malaysia
[4] Department of Human Anatomy, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Selangor, Malaysia

ABSTRACT

Embryology is a critical subdiscipline in medical education, focusing on human body organ development and providing a foundation for understanding developmental anatomy. However, traditional teaching methods using static 2D graphics in textbooks may hinder students' comprehension of the complex 3D embryonic growth processes. To address this, multimedia approaches, such as animations, videos, and interactive tools, have been explored for effective embryology education. This scoping review identifies five key elements of successful multimedia teaching in embryology: multimodal integrated instructional content, cognitive load-reduction strategies, cognitive engagement and physical interactivity, learner-controlled multimedia instruction, and development of tacit knowledge. These strategies promote active learning, enhance students' understanding, and foster critical thinking skills. Future research should focus on evaluating the impact of multimedia approaches on students' engagement, attitudes, and competency development. Embracing multimedia in embryology education can improve medical students' clinical understanding and support effective medical practice.
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Corresponding Author:
Razif Abas, PhD
Email: razifabas@gmail.com
Tel: +603-97692479

INTRODUCTION

Embryology is a subdiscipline that deals with the study of human body organ development, and its learning objective is to provide a solid basis of human developmental anatomy. Differentiation and growth have been connected to assist reproduction technologies through a variety of processes, including birth, embryo and fetus development, zygote creation, gamete generation, and fertilization (1). Before birth, organs and congenital anomalies' complex topographical relationships necessitate knowledge of embryogenesis (2). Paediatrics and obstetrics education include it as an essential component (2, 3).

Aside from this, embryology is covered in medical school as part of the preclinical basic scientific curriculum (4, 5). Students' foundational knowledge of embryology is laid during the pre-clerkship years. Anatomical surgery, ear-nose-throat surgery, general surgery, paediatrics, obstetrics and gynaecology, and the study of congenital abnormalities that emerge before birth all can benefit from embryology's findings (2, 6, 7).

The design of embryology curricula in medical schools varies significantly (8), with various approaches and modalities used in teaching practices comprising a wide range of educational materials. In most medical schools, students study embryology using textbooks in addition to lectures. Although this book encompasses much information, its static and two-dimensional (2D) nature prevents it from providing a comprehensive understanding (2). Because textbooks use 2D graphics of cross-sections and static schematic images, students could find it challenging to study and comprehend 3D embryonic growth processes in a developing human body (2, 9).

Furthermore, most instructors aim to choose appealing strategies and modalities to deliver embryonic development knowledge to students effectively because using such appealing modalities, particularly concerning the development of a properly grown organism from a fertilized egg, will help students understand the material (10, 11). Model organism-based approaches, such as those employing the nematode C. elegans and fruit fly D. melanogaster as models, occasionally are used in education (12). They function as one of the tools for teaching fundamental concepts, but they also have drawbacks, such as the fact that they are not species-specific and contain a wide range of features that can lead to learners misunderstanding the process. (11).

Furthermore, the prices of commercial models for teaching practice and embryology lessons are exorbitant and unaffordable in some cases (10). As a result of these circumstances, some teachers have decided to continue teaching embryology using traditional methods and approaches. Aside from this, regardless of specialization, all students or new doctors participate in an embryology program. Beginning with fundamental principles in the early years of medical school and progressing to clinical specialities, the subject of embryology is to be taught at the appropriate degree and depth (13). Hence, knowing about embryology can be incredibly beneficial in improving clinical understanding of required treatments (1, 2, 8, 14).

The number of hours allotted to teaching embryology subjects also raises some issues. Currently, no duties or regulatory criteria are in place for the incorporation of embryological content in medical curricula (15). Instructors limit their contact hours in laboratories due to scheduling constraints and provide instruction on only a few subjects, impacting learning outcomes, as well as the amount of knowledge during a particular period of time (4). Aside from this, course length must be acceptable to maintain attention while providing sufficient levels of detail. Teaching style and delivery should be interactive while also being informative. Trying to engage in problem-based teaching activities and managing content become more complex as time constraints increase (10).

Multimedia teaching entails using technology to combine many media types – such as text (alphabetic or numeric), animation, symbols, graphics, music, photos, and video – to aid learning and memorization. Educational multimedia applications' design quality and sophistication are usually good enough to blend the many parts of cognitive processes to best replicate traditional instruction (16). According to the literature, students in a fully interactive, multimedia-based e-learning environment performed better and were more satisfied than students in a traditional classroom or in a less-interactive e-learning environment (17). Multimedia content helps vary and enhance the learning process, which can lead to better knowledge retention. Sometimes it even can demonstrate complex ideas better than an instructor can verbally, and students have more opportunities to engage with the content and understand it better. Using multimedia can make learning activities more interesting and easier, not only improving students' listening skills, but also their audiovisual, reasoning, and comprehension skills (18).

A multimedia approach to teaching embryology is more favourable than a traditional teaching method, making it less difficult for students to understand concepts, including human development stages (19). They also experience better comprehension when using multimedia teaching materials, which include movies, animation, and images (19). Multimedia have improved students' learning gains, particularly in life science studies (20), and a multimedia approach in embryology can be useful in cultivating an understanding of embryology knowledge, as this approach can generate mental imagery visualization through 3D and dynamic diagrams more easily. Thus, the present study's goal was to explore the breadth of literature that reported factual evidence of effective multimedia teaching in embryology education, as well as provide suggestions for future practice. Instead of conducting a systematic review, a scoping review was conducted to uncover literature that particularly addresses successful multimedia elements in embryology anatomy (21).

METHODOLOGY

To identify the important features of effective multimedia teaching in embryology education, a scoping review was conducted in accordance with a scoping review framework by Levac et al. (2010) (22) and Westphaln et al. (2021) (23): Stage 1: Identifying the research question; Stage 2: Identifying relevant studies; Stage 3: Selecting studies; Stage 4: Data visualization; Stage 5: Data collection, summarization, and reporting; Stage 6: Consultation.

Identification of Initial Research Question

The literature was examined using an initial study question: "How effective are various multimedia elements and strategies at teaching human embryology compared to traditional didactic approaches?" Within this frame of reference, an "effective teaching strategy" was described as a method tested in an interventional multimedia study with visible and quantifiable beneficial outcomes.

Identification of Relevant Studies

A discussion among authors led to identification of potential keyword selection, which were then counter-checked in the Medical Subject Headings (MeSH) database. Three search terms with the Boolean combination were identified, tested and refined with multiple test searches to ensure adequate pool of resources. The final search terms with the Boolean operation were as follows: "Multimedia" AND "Embryology" AND "Teaching" AND "Effect." Academic Search Complete, CINAHL, SportDiscus, Medline, and Scopus databases were used to conduct a full systematic search, which was completed on January 20, 2023. The included study's reference list was vetted as part of a manual search. The cases that were discovered also were examined for the original report. Following the selection of suitable citations, an eligibility screening process was conducted. Each retrieved study was subjected to the following inclusion and exclusion criteria, which were determined through discussions among the authors. As for inclusion criteria, studies must involve human embryology, healthcare-focused populations of students, and must entail teaching or learning. Generally, entire articles written in English that described the effectiveness of using multimedia teaching methodologies for embryology curricula were included in this scoping review. Review articles, editorials, opinions, theses, and any other works that did not meet the eligibility criteria were disqualified.

Study Selection

There were three stages to the study-screening process: title screening; abstract screening; and full-text screening. The titles were screened using the following inclusion criteria: (1) the title is written in the English language, and (2) the title reflects the use of multimedia approach and embryology teaching. Subsequently, the abstracts were then assessed using the eligibility criteria for abstract selection, which include: (1) the abstract indicates that the paper is an original article; (2) the abstract highlights multimedia teaching strategy in embryology learning; (3) the abstract presents evidence of quantitative or qualitative evaluation of multimedia approaches in embryology teaching. Abstracts that fulfilled these criteria were selected, and the full articles of these abstracts were screened using established full-article eligibility criteria, namely: (1) the article describes a well-designed research intervention; (2) the article elaborates the multimedia strategy of approach that has successfully conducted during embryology teaching; (3) the article elaborates the methods of outcomes measurement; and (4) the article provides evidence of evaluation of the embryology teaching methodologies that utilise multimedia approach.

The search results were exported to the bibliographic software programs EndNote (Clarivate Analytics; Philadelphia, PA) and Microsoft Excel spreadsheet (Microsoft Corp.; Redmond, WA). Two researchers were assigned to the task of selecting full-text papers, as advised (24, 25). The initial agreement rate for preselection was 63.6 per cent (7/11), and the articles that were chosen were settled by discussion between two authors (RA and SNHH). Subsequent seven articles were used in the final study for data extraction and charting. The research selection procedure was reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA-ScR) flowchart as recommended by Tricco et al. (2018) (26).

Charting the Data

A data-extraction form was designed and adjusted iteratively for the articles (27). To chart the main information from the selected articles, the following table was created with the following items: author(s) and year of publication; study design; multimedia approach; result measurement; and a brief limitation. An independent researcher extracted data from each featured article, which another researcher then double-checked for accuracy and missing data. The entire team re-evaluated selected data containing conflicting information, and a final decision on the charted data was achieved through consensus. The extracted data items were specified, and an explanatory document was created with thorough descriptions and examples.

Collating, Summarizing, and Reporting the Results

A content analysis through thematic construction of the extracted data was conducted by two researchers (RA and SNH) to identify effective multimedia approaches or strategies in teaching embryology by using the ATLAS.ti software version 9. The initial step involved profiling the extracted multimedia approaches or strategies from the extracted data and grouping them into several categories according to their similarities. Subsequently, the combinations of several categories expressing with common features were grouped several themes. Each of the themes and categories was given a name, which was operationally defined according to its underlying data. The selected themes and categories were presented to the other co-researchers in the team (RD and NSO), and a discussion was made to either to accept or revise each of the theme and categories (28).

Consultation

Three anatomists and two embryologists who have more than a 6-year experience of in teaching, and assessment in undergraduate medical curricula were consulted after the article selection process. The results were triangulated with experts' opinions and accordingly reviewed, renamed, and recategorized. The final themes were defined and presented in tabular and narrative forms.

RESULTS

Literature Search

Based on the keyword search, 455 articles were found in the databases, with 179 duplicates removed. The remaining titles were evaluated against the eligibility requirements, and 187 articles were eliminated. The eligibility criteria then were applied to the remaining 89 publications' abstracts. As a result, 45 abstracts were deleted, primarily because they suggested that the publications were not original research, did not completely describe multimedia approaches for embryology teaching, or could not provide quantitative or qualitative analytical data. The remaining 44 abstracts' entire articles were retrieved and reviewed against the qualifying requirements. Finally, the complete text of the seven articles that met all the requirements was examined (19, 29-34). Generally, most of the studies used animation and videos as their multimedia approach. The review procedure is reported in the PRISMA-ScR flowchart as illustrated in Fig. 1.

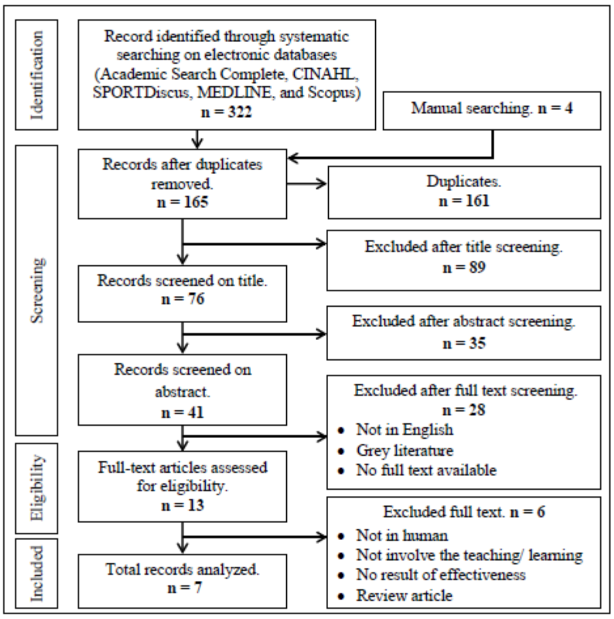

Figure 1: Flow diagram of screening process. A number of 161 duplicates were found out of 326 records and were removed during the initial procedure.

Selected Articles' Study Characteristics

The final seven articles were published between 2008 and 2023, with four appearing during the last five years of this period (31-34) (Table I). The research was conducted on several continents, including Europe and North and South America, with most originating in Asia (31-33). To evaluate teaching effectiveness, all the selected studies employed a cross-sectional method with a questionnaire as the data collection method. Four studies did not use a control group for comparison (19, 30, 33, 34), and in three studies the efficacy of the embryology training interventions were nonsignificant compared to controls (19, 31, 33). For the analysis, all the research employed quantitative methods, but two used a combination of quantitative and qualitative methods (30, 34), with no studies using solely qualitative methods.

Synthesized results: Multimedia in Embryology Teaching

This study found four multimedia embryology teaching tools that have been shown to be effective: animation; movie; video; and screencast. Two studies examined the effectiveness of the multimedia teaching approach during the general embryology classes (29, 32), three investigated systemic embryology (19, 30, 34), and the remaining two studies were both analyzed general and systemic embryology (31, 33). Table II summarises the data on instructional strategies and outcomes found in the included studies.

Table I: Studies Characteristics

Auhors and Location of the Study	Objective Study	Multimedia Approach	Study Design	Findings	Limitation
Marsh et al., 2008; University of Cincinnati College of Medicine, USA	Develop Web-based learning modules (computer-assisted-instruction modules) in early embryonic folding and neural tube development	Study group: Animated 2D cross-sectional and 3D graphics Control group: 3D models that a student can manipulate independently	1) Short-term retention: The effectiveness via comparison with control group-one-tailed student's t-test	After 14-quiz questions: 1) Short term retention, two cohorts were compared; Cohort 1: **p=0.02** for the cohort students which have experienced this module traditionally and Cohort 2: p=0.27 for the cohort students who first exposure to this module	1) Less sample size 2) No inclusion and exclusion criteria were mentioned 3) For long-term retention- the comparison of 16 months was only performed in one cohort group only
			2) Long-term retention (4 months and 16 months): The effectiveness via comparison with control group - one-tailed student's t-test	2) Long-term retention, two cohorts were compared; Cohort 1: p=0.29 (4 months) and Cohort 2: **p=0.005** (4 months), **p=0.04** (16 months)	
Moraes and Pereira, 2010; State University of Campinas, Brazil	To develop and evaluate new educational materials and a teaching methodology based on multimedia approaches to improve the comprehension of human development during Human Morphophysiology class	Animation, movies and video of both normal development and anomalies (systemic embryology)	The series of embryology lectures was divided into two parts: 1) Theoretical classes (1 h and 40 min), the development of the body's structures was explained using illustrations, animations, and videos 2) Discussion-based exposition classes (1 h and 40 min), the clinical history of each case was provided and macro- and microscopic, ultrasound and other selected autopsy images, as well as movies of corrective surgeries	No statistically data were mentioned, two parameteres were measured: 1) Mostly scored based on means and standard deviations of the students' marks on seven exam-averages score more than 5.0 (the minimal approval limit) 2) Number of attitudinal perception of the students, presented by dimension- mostly in "Comfort Zone" 3) Interviews from students suggesting their great enthusiasm for this type teaching approach	1) No control group to compare 2) No statisically significant of comparison

Table I: Studies Characteristics (continued)

Auhors and Location of the Study	Objective Study	Multimedia Approach	Study Design	Findings	Limitation
Evans, 2011; Brighton and Sussex Medical School, UK	This study examines the use of and student reaction to a set of screencasts introduced to accompany embryology lectures within a second year module via managed learning environment (MLE)	Five mini-lecture screencasts (systemic embryology topic) were produced as digital recordings of computer screen output with audio narration	1) Student knowledge- data for each screencast were focused on nine separate items	1) Student usage- one screencast being downloaded 362 times and another just 67 times, the average number of repeated downloads per student approximately three times, some students downloaded a single screencast up to 16 times, the timing of downloading showed the most popular time and day for downloading being 8 PM and Wednesday, respectively	1) No control group to compare 2) Authors did not mention the criteria of screencasts selection in the part of “student reaction” and “student attainment”
			2) Student reaction- evaluation via end-of module anonymous questionnaires using a student’s t-test and open qualitative comments about the screencasts which categorized into common themes	2) Student reaction- students were statistically more positive (**p<0.05**) about the growth and development theme lectures than either of the other themes, no statistical difference between the student responses for the embryology lectures and the embryology screencasts, qualitatively, most of the student attribued at “best aspect” section	
			3) Student attainment- two chohort of student achievement in end-of-module written examination questions using a student’s t-test	3) Student attainment- the 2009/2010 results showed that students performed well in each of the three themes, although students scored an average of 19.4 out of 25 (78%) for the growth and development theme which was found to be significantly higher than the other two themes (**p<0.05**), student results for the growth and development theme were found to be statistically higher for the 2009/2010 academic year as compared to 2008/2009 (**p<0.05**)	
Chen and Hua, 2017; Luohe Medical College, China	To improve the learning effect of histology and embryology course in the higher vocational college students via 3D teaching method	Micro 3D video teaching method via mobile technology (no specific embryology topic was mentioned)	Randomly selected 2 class from grade 2016 of three years clinical specialty were 165 and 166, one class was randomly assigned to the experimental group and the other one as the control group, satisfaction and theoretical analyses were measured	1) Experimental class students on the course of satisfaction were significantly better than that in control classes, (**p<0.05**) 2) Experimental class with the new teaching mode of the classroom using the questionnaire of the star test, the theoretical results are significantly higher than the control (**p<0.05**)	1) No statisically significant of comparison 2) No inclusion and exclusion criterias were mentioned 3) Authors did not mention either undergraduate or postgraduate participants
Narayanan et al., 2018; Sri Manakula Vinayagar Medical College, India	1) To estimate the the score improvement after analogy and 2D animation teaching among unimodal and multimodal learners 2) To estimate the difference in pre-test, post-test, and follow up score between unimodal and multimodal learners, The topic involves environment of gametogenesis, 1–3 week of development and neural folding	Analogies and simple 2D animations made with Microsoft powerpoint software	Quasi-experimental study with pre-test, post-test design of a single group and a follow up group (7 months after), among first yeat medical student		1) No inclusion and exclusion criteria were mentioned
			1) Comparison between unimodal and multimodal via paired sample t-test Unimodal: single modality of learning Multimodal: combination of modalities	1) There was significant improvement in post-test score among the unimodal (**P<0.001**) and multimodal learners (**p<0.001**), post-test score was (**p=0.018**) upon compared between the two groups, the multimodal learners performed better than the unimodal learners	
			2) Comparison between unimodal and multimodal in analogy perception scale via independent sample t-test	There was no significant difference in the perception of animations and analogies between the groups and long-term retention of knowledge, except “the use of 2D animations helped in recollection of the subject during exam preparation” (**p=0.030**)	
			3) Comparison between unimodal and multimodal in 2D animation perception scale via independent sample t-test		

Table I: Studies Characteristics (continued)

Auhors and Location of the Study	Objective Study	Multimedia Approach	Study Design	Findings	Limitation
Nuzhat and Monshi, 2019; Imam Muhammad Ibn Saud Islamic University and Dar ul Uloom University, KSA	1) To examine the efficiency of using the multimedia (animation and videos) and the 3D models in understanding embryology among medical students 2) To investigate the impact of these methods in teaching, learning styles, studying time and academic performance	Multimedia (animation and videos) and the 3D models were utilized for teaching embryology to medical students (n=78) during Growth and development module (no specific embryology topic was mentioned)	Pre-tested questionnaire comprising of close-ended questions in line with the study objectives. The questionnaires were distributed after few teaching sessions using the new methodology and students were asked to respond in their free time: 1) Objective 1: efficency	81.6% of the students prefer the 3D video and animation over the power point (39%), Traditional Board Lecture (29.70%), and the Web-based Learning (26.3%). 78.2% of the students agreed that it is the most appropriate method at their level. 81.6% of the students approved that this method increased their interest in learning embryology. 68.8% of the students think that the 3D video and animation maintained their attention	1) No control group to compare 2) No statisically significant of comparison 3) No inclusion and exclusion criteria were mentioned
			2) Objective 2: impact	85.5% of the students improved their understanding and retention of lecture knowledge (80.8%) by the use of the 3D video and animation when compared to Traditional Board Lecture (27.6%), and the Web-based Learning (28.6%). Majority of the students (77.9%) think that the 3D video and animation should be applied on the other subjects and also can be applied standalone for teaching embryology (70.1%). The 3D video and animation have aided the learning style of (78.4%) of the students, reduced their study time (70.7%) enabling greater participation in the class (56%) eventually leading to improvement in their academic performance (83.1%).	
Upson-Taboas et al., 2019); Indiana University, USA	The authors evaluated both short-term learning comprehension of complex 3D structural changes over time to further elucidate the usefulness of the animations by assessing what improvements could be made in the future	Six web-based cardiovascular embryology animations	1) Cardiovascular embryology pretest- consisted of approximately four to seven multiple-choice questions with five answers option	Participant post-test scores were statistically significantly higher than matched pretest scores, ranging from 14 to 51% of correct answers on pre-tests (average 28%), and 62– 80% on post-tests (average 69%) (p<0.001 regardless of the animation)	1) No control group to compare
			2) Cardiovascular embryology post-test- similar manner as in pretest, pretest and post-test scores were analysed using paired students t-test		
			3) Cardiovascular embryology animation assessment survey via qualitative analysis	2) Participants found all of the animations very easy to use (83%) and very effective for learning the material (74%). The animations were overwhelmingly found to aid in answering post-test questions (94%), and the post-test questions were found to be adequate for assessing what was learned (92%).	

Table II Elements of Multimedia Teaching explored in the included studies

Elements of multimedia teaching	Number of articles (n)	Findings
Effectiveness of multimedia approach during general embryology classes	2	Two multimedia teaching tools found to be effective in general embryology teaching namely 2D animation and 3D graphic[a,b]
Effectiveness of multimedia approach during systemic embryology classes	3	Two multimedia teaching tools found to be effective in systemic embryology teaching namely animations and screencasts[c,d] One multimedia teaching tools (animation) did not mention the effectiveness in systemic embryology teaching[e]
Effectiveness of multimedia approach during both general and systemic embryology classes	2	Two multimedia teaching tools found to be effective in both general and systemic embryology teaching namely 3D animation and video[f,g]

[a]Marsh et al., 2008; [b]Narayanan et al., 2018; [c]Evans, 2011, 2018; [d]Upson-Taboas et al., 2019; [e]Moraes and Pereira, 2010; [f]Chen and Hua, 2017; [g]Nuzhat and Monshi, 2019

Results of the thematic construction of data

Multimodal integrated instructional material, cognitive load-reduction strategies, cognitive engagement and physical interactivity, learner-controlled multimedia instruction, and development of tacit knowledge were the five main multimedia themes of effective embryology teaching that the thematic analysis identified (Table III). Multimodal integrated instructional refers to using various learning tools and instruction modes. This theme not only highlights multimedia tools and instruction but also emphasizes using non-multimedia learning tools (29, 31, 32), as well as authentic real-life instruction as an adjunct to a multimedia embryology learning environment (19, 32). Among multimodal integrated instructions identified in this review were teleconferencing web tools (29), web-based instruction and animation (29, 34), multimedia tools (19), and smartphone and mobile applications (30, 31). Furthermore, the multimodal instruction identified in this review includes instruction that describes both normal and abnormal development of body structures (19), provides students with supplementary printed materials (19), the use of authentic real-life instruction and incorporates formative assessment (30).

Cognitive load-reduction strategies imply instructional techniques that reduce total cognitive load by reducing the extraneous load (i.e., unwanted load that hinders learning) and managing the intrinsic load (i.e., mental load related to learning). The underlying elements under this construct pertain to strategies that eliminate distraction, improve organization of embryology instruction (i.e., contiguity effects, dual-modality, integrated information, and organized instruction) (30, 32), stimulate prior knowledge (30, 31), divide instruction into smaller components (32), and use illustrations to depict complex dynamic events (34).

Likewise, cognitive engagement and physical interactivity reflect the strategies that direct learners' focus, stimulate mental imagery, and stimulate students' interactivity. These strategies were achieved by using various visual cues, namely static and dynamic diagrams and animation (29, 32), analogies (32), colour coding (32), and 3D diagrams (19, 33). However, interactivity could be reflected by using interactive lectures (19), interactive animation (34), and strategies that foster interaction among students (19, 30, 31).

Next, it is evident that most of the multimedia elements identified in this study let the learner control these learning tools, thereby allowing them to set the pace for their own learning. For example, using multimedia splash pages, front pages, or landing pages allows students to navigate multimedia content more freely, based on their needs, without losing their direction (34). Likewise, using timelines and frame-based animation allows students to control animated diagrams based on their own pacing (34).

The final theme, development of tacit knowledge, is explicit through several underlying elements, namely the inclusion of affective learning (19), student reflection (30), self-study facilitation (19, 31), and post-class learning using multimedia instruction (31). These findings reflect that effective multimedia embryology instruction not only emphasizes cognitive learning domains but also promotes the development of skills and affective learning.

DISCUSSION

This scoping review identified five functional multimedia elements that have been proven to be effective in embryology teaching. Despite the scarcity of well-designed studies in multimedia-based embryology teaching, the data generated from this review are comprehensive and consistent across all included studies, thereby reflecting its reliability. Interestingly, the multimedia elements that emerged from this review not only emphasize the cognitive learning construct but also incorporate the development of psychomotor and affective learning through the enforcement of tacit knowledge. It should be noted that the generated multimedia elements correspond with several educational and instructional design principles, namely multimodal learning, integrated instruction, management of cognitive load, and active learning.

The first multimedia element identified in this review is multimodal integrated instructional material, which encompasses tools and content instruction used in embryology teaching. In a broad sense, multimodal describes using various sensory modes (i.e., auditory, visual, spatial, kinesthetic, and linguistic) in attempts to develop knowledge schema or meaning from learned information (35). Multimodal learning is underpinned by several core elements, namely semiotic resources, inter-semiotic relations, and modal affordance (36). In this review, semiotic resources could be reflected by using integrated embryology and clinical applied knowledge, which were introduced in the form of authentic triggers or scenarios. Being exposed to real-life scenarios allows students to make sense of embryology or anatomy input easily (37). Likewise, using multimedia tools in embryology teaching stimulates inter-semiotic relations within knowledge, allowing for transformation of normal text and diagrams into certain digital features, such as text hyperlinks and digital layering of embryological structures (38). This form of instruction can help students examine dynamic interactions among various forms of information utilized in the multimedia environment, leading to a solid understanding of the knowledge.

In addition, using different delivery platforms for multimedia tools (e.g., mobile applications, computer applications, web-based instruction, and teleconferencing software), as well as their simultaneous use with non-multimedia tools (e.g., lectures, printed

Table III: Multimedia Themes and Subthemes in Effectiveness of Embryology Teaching

Theme	Subtheme	Element in Multimedia Teaching
A. Multimodal integrated instructional material	Multimedia tools usage	Teleconfering web tool usage[1]
		Web-based animation usage[1,7]
		Multimedia tool[2]
		Smartphones usage[3]
		Web-based instruction[3,6]
		Mobile apps usage[4]
	Basic and applied instruction integration	Introduction of both normal and abnormal development[2]
	Multimedia and non-multimedia instruction of combination	Provide students with supplement printed materials[2]
		Non-multimedia and multimedia instruction usage simultaneously[1,4,5]
	Authentic instruction usage	Authentic real-life instruction or trigger[2,5]
	Formative assessment incorporation	Incorporation of formative assessment[3]
B. Cognitive load reduction strategies	Reduce extraneous load	Instruction with several menus or categories organization[2] Reduce extraneous elements[2] Spatial contiguity[2] Integrated instruction[3] Dual modality[3,5] Temporal contiguity effect[3,5]
	Intrinsic load management	Recall prior knowledge[3]
		Chunking mechanism[3]
		Preclass learning using multimedia instruction[3,4]
		Intrinsic load minimization[5]
		Pretraining to stimulate prior knowledge[5]
		Segmenting animation[5]
		Illustration of complex dynamic events[7]
C. Cognitive engagement and physical interactivity	Direct learners' attention focus	Web-based animation usage[1,7] Static and dynamic graphics[2] Colour coding[5] Analogies5
	Mental imagery stimulation	Static and dynamic graphics[2] 3D images and instruction usage[4,6] Animation3,5
	Interactivity stimulation	Interactive lectures[2]
		Foster interactivity[2,3]
		Students interaction encouragement[2,4]
		Interactive animation[7]
D. Learner control multimedia instruction	Learner control	Learner control[7] Learner pacing[7] Splash page/front page of multimedia material[7] Timeline and frame-based animation[7]
E. Development of tacit knowledge	Instill value of learning	Inclusion of affective learning[2] Student's reflection[3]
	Self-directed learning enhancement	Self-study facilitation[2,4] Post class learning using multimedia instruction[4]

[1]Marsh et al., 2008 (four elements); [2]Moraes and Pereira, 2010 (fourteen elements); [3]Evans, 2011 (eleven elements); [4]Chen and Hua, 2017 (seven elemnts); [5]Narayanan et al., 2018 (ten elements); [6]Nuzhat and Monshi, 2019 (two elements) and [7]Upson-Taboas et al., 2019 (eight elements).

materials, and atlas diagrams), as mentioned in the included studies, could enforce the modal affordance concept of multimodality, as each tool offers its own advantages in promoting understanding (Jewitt, 2013). For instance, digital instruction is more effective at stimulating 3D mental imagery, while printed materials allow students to take notes and sketches of embryological drawings. Thus, it could be argued that modal affordance optimizes the functions of instructional materials used during the embryology learning session.

The second functional multimedia element elicited from this review is the cognitive load-reduction strategy. In the context of educational psychology, cognitive load refers to information that enters human working memory systems during learning (39). According to instructional design theory, under cognitive load theory (CLT), a learner effectively can understand new knowledge if working memory is not overburdened with information, i.e., learning is optimized when total cognitive load does not exceed working memory's storage and processing capacity (40). CLT outlines (41) three types of cognitive load, namely intrinsic load (i.e., an instruction's inherent complexity), extraneous load (i.e., an unwanted load that hinders learning), and germane load (i.e., mental effort used to process intrinsic load) (42).

In this review, several cognitive load-reducing strategies were identified from the included studies. For instance, the dual modality strategy (i.e., simultaneous use of audio and visual input) optimizes working memory capacity, as both auditory and visual centres of working memory are being utilized during learning (Ginns, 2005). Likewise, concurrent presentation of pictorial materials and related text (i.e., spatial contiguity), as well as verbal explanations of diagrams (i.e., temporal contiguity) used in the multimedia instruction, could help reduce the extraneous load, as students do not need to integrate this information mentally (41, 43). Thus, their mental resources are reserved for processing actual instruction. Moreover, one study explicitly highlighted the systematic organization of multimedia embryology instruction as an effort to eliminate distractions (19), which consequently would lessen the extraneous load on students (44).

In addition, this review identified several strategies for managing intrinsic load, and one of these strategies is the stimulation of prior knowledge through pre-class learning using multimedia instruction (Chen and Hua, 2017; Narayanan and Ananthy, 2018). Previous studies have found that stimulation of prior knowledge triggers retrieval of information from long-term memory into working memory, which demands fewer cognitive resources compared with when learners need to retrieve this stored information on their own (i.e., self-discovery) (45, 46). It also was evident that multimedia embryology instruction from the included studies incorporated chunking mechanisms into the instructional design, as this information was presented in small segments (30, 32). The segmenting principle describes the delivery of small, isolated chunks of information that eventually were combined into one single information unit so that the learner could understand the isolated elements (47). This principle was demonstrated to elicit influence on intrinsic load, as the limited working memory could process only several chunks of information at one time (48). Thus, it has been postulated that multimedia elements identified in the included studies could have reduced students' total cognitive load, thereby enhancing students' understanding.

With the reduction in cognitive load, it could be argued that students cognitively were engaged when learning embryology through multimedia instruction. This postulation is aligned with the third functional multimedia element generated from this review, i.e., cognitive engagement and physical interaction. Cognitive engagement refers to a learner's ability to invest consciously and exert his or her mental effort in processing information (49). This effort could be reflected through learners' ability to sustain their attention and construct meaningful schema in their working memory throughout the learning process (50, 51). In this review context, it is evident that the multimedia instructions stimulated students' attention focus and mental imagery through various strategies. For instance, using analogies and color coding identified from the included studies (19, 30, 32, 52) could be a form of visual cueing, a powerful tool in directing students' attention toward relevant information, and consequently optimizing visual working memory function (53). Likewise, using animation and static graphics identified in the included studies could impact learners' visuospatial and spatiotemporal abilities, as animation has been proven to elicit high performance in identifying motions, while static pictures outperformed animation in identifying spatial arrangements (54, 55). Furthermore, animation and learning activities incorporated in multimedia instruction could stimulate interactivity during the learning process.

Furthermore, embryological multimedia instruction in this review was found to promote students' interactivity. It was reported that interactive multimedia improve students' critical reasoning, responsiveness, and motivation toward learning targeted content, thereby enhancing learning (56). Multimedia instruction's learner control features – the fourth identified multimedia element of this review – are aligned with the segmenting principle of the cognitive theory of multimedia learning (CTML), whereby instructions are categorized into several parts or interphases that the learner can control (57). Instilling learner control in instructional materials is a powerful method to promote student-instruction interactions, and it also provides opportunities for students to navigate instructions at their own pace and convenience (58).

Interestingly, this review also elucidated multimedia embryology instruction's potential strategies in promoting the development of tacit knowledge and skills – identified as the final theme of this review. In general terms, tacit knowledge is the implicit ability that is less recognizable and operates below the conscious level, such as critical thinking, competent level, experience, deeds, attitudes, and values (59). Multimedia instruction's learner control feature could have facilitated tacit knowledge development, as students were able to conduct their own self-revision after formal embryology classes, as a form of autonomous self-regulated learning (60). Furthermore, the aforementioned integrated clinical embryology knowledge and multimedia instruction's interactivity features could stimulate critical thinking and create experiential learning environments that allow students to reflect on their own learning (61).

Future Research Directions

These techniques' impact on students' engagement, attitudes, knowledge, skills, behaviour change, organizational practice, and patient benefits should be evaluated systematically using Kirkpatrick's levels of educational evidence in medical education (62). Anatomy educators indirectly could become proficient instructional designers and learning facilitators as a result of teaching methodology research, ensuring the smooth execution of teaching and learning activities. This focused effort would be able to demonstrate excellent approaches in teaching and understanding embryology. Furthermore, the results of this scoping review highlight three important competencies that could be achieved through multimedia embryology learning, namely: (1) higher level cognitive competency through clinical integration of embryological input; (2) affective learning through tacit knowledge component; and (3) digital skills, that is a prerequisite for online or multimedia learning. Drawing to the wide spectrum of competency domain that could be achieved through this instructional material, a wider variety of assessment method should be designed to evaluate for the achievement of these competencies. However, further work needs to be done to establish the utility of these assessment tools following the multimedia embryology teaching, as to ensure that embryology syllabus remain relevant especially in medical school.

Study Limitations

This evaluation is based on a conceptual framework that encompasses only an overview of multimedia teaching methodologies in embryology anatomy. Because the terms “Multimedia AND Embryology AND Teaching AND Effect” were not employed as search methods, studies employing specialized terminology on multimedia teaching – such as text (alphabetic or numeric), symbols, graphics, and photos – may have been overlooked, thereby limiting the initial number of search articles. Furthermore, because no English translations were provided, a few articles potentially might be viewed as exclusionary.

Moreover, because of adherence to the scoping review’s inclusion criteria, prospective multimedia approaches, such as embryology instruction, that employ illustrations with augmented reality (AR), or virtual reality (VR) were not examined significantly in this evaluation. The selected articles were chosen because they provided clear techniques for measuring the results – one of the criteria examined in this review. Because AR and VR are relatively new teaching modalities in anatomy education, only a few studies have been conducted in this area employing a rigorous study design and well-designed methodology.

CONCLUSION

Medical students view embryology as a valuable and applicable skill for their future clinical practice. This study identified five key components of efficient multimedia education in embryology: multimodal integrated instructional content; cognitive load-reduction strategies; cognitive engagement and physical interactivity; learner control multimedia instruction; and development of tacit knowledge. Furthermore, because no single effective multimedia teaching method in embryology education exists, this review recommends multimodal approaches to teaching. Finally, anatomy educators are encouraged to apply proven educational theories while building and developing creative approaches for embryology and other subdisciplines of anatomy, such as gross anatomy, comparative anatomy, neuroanatomy, and histology.

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